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Root and canal configurations of mandibular molars using CBCT, with an emphasis on middle mesial canals

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DECLARATION

I, Sheree Tredoux, hereby declare that this dissertation entitled, **Root and canal configurations of mandibular molars using CBCT, with an emphasis on middle mesial canals,** which I herewith submit to the University of Pretoria in partial fulfilment of the requirements of the degree: MSc (Dent) is my own original work, and has not been submitted for any academic award or qualification at this or any other institution of higher learning.

______________________ ______________________

Signature Date

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ABSTRACT

Introduction: An extensive knowledge of dental root and canal anatomy is essential to clinicians performing endodontic treatment. It is well-known that dental anatomy may be complex and display significant variation. **Aim:** The aim of the present study was to classify the root number and the root canal configurations of human mandibular first and second molars in a South African sub-population using CBCT. **Materials and methods:** The study design was a retrospective cross-sectional descriptive study. The sample size included 753 molars. The CBCT images of each individual mandibular first and second molar were evaluated in coronal, sagittal and axial views. Classification of the canal configurations of each root was made using the Vertucci classification system, including the additions proposed by Sert and Bayirli. Classification of root number was described as one, two, three, or four-roots. **Results:** Root anatomy: Two-rooted configurations were demonstrated in the majority of first and second molars (98.7% and 94%). One- and three-rooted molars were rare with a prevalence ranging from 0.3% to 2.9%. Half of all three-rooted molars presented with two distinct mesial roots. Four-rooted molars were found in second molars only (0.5%). Canal anatomy: The most common canal type in the mesial roots of mandibular first and second molars was Type IV (50% and 38%) followed by Type II (21% and 24%). The most common canal configuration in the distal roots of the first and second molars was Type I (50% and 81%) followed by Type V (20% and 10%). More than two mesial canals in mandibular first and second molars were present in 21% and 17% of the sample. More than two distal canals were demonstrated in first and second molars in 7% and 2% of the sample. C-shaped canal systems were found in 0.5% of first molars and 7.7% of second molars. Sex and age had no correlation to root or canal configurations. **Conclusion:** More than two mesial canals were found in about one-fifth of the sample. It is important for clinicians to be aware that a number of mandibular molars may present with more intricate anatomy than expected during endodontic treatment and that this may affect treatment outcomes.

LIST OF ABBREVIATIONS

CBCT	Cone beam computerised tomography
RESCOM	Research committee (School of Dentistry, University of Pretoria)

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CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

An extensive knowledge of dental root and canal anatomy is essential for clinicians aiming to perform successful endodontic treatment. It is well-known that dental anatomy may be complex and display significant variation. Previous studies have demonstrated that a significant proportion of different tooth types may present with additional internal anatomy.[1] This assertion has been supported by numerous studies on different tooth types.[2–19]

Additional root numbers have also been reported in the scientific literature. In the human dentition, for example, mandibular molars normally present with two roots, but a third root may exist in some instances.[20]

Habib *et al.*[21] suggested that variations of root number and canal configurations in the human dentition may be related to hereditary and/or ethnic differences between population groups.[21] This sentiment is shared by Kuzekanani and Najafipour[20] who reported a correlation between root formation and racial, genetic and external factors. Geographic area has also been suggested to play a role in the variation of dental anatomy.[22]

There are several classification systems which describe root canal anatomy which have previously been used to classify the human dentition. The Weine *et al.,*[23] and Vertucci[1] classification systems are perhaps the best known and most widely used classifications. The Vertucci classification system has been used more frequently,[24] however this classification is limited when describing teeth that have more than two canals per root.[22]

In 2004 Sert and Bayirli[25] described 15 more root canal configurations in addition to Vertucci's original classification system in order to describe complex root canal anatomy. This additional classification has previously been used in anatomical studies, particularly when describing the anatomy of molar teeth.[25–27]

Locating and treating all root canals may be difficult.[28] Research has shown that a failure to locate all the root canals present during endodontic treatment decreases the chance of retaining a tooth.[28] The presence of additional roots and the canal systems is considered to be one of the leading causes of endodontic treatment failure in molar endodontics.[20]

The middle mesial canal is an additional root canal located in the anterior root of lower human molar teeth.[29] It has been suggested that this canal is often missed during root canal treatment.[29] It may be extrapolated that an inability to detect and treat this additional canal may lead to an increased failure rate of root canal treatments of lower molar teeth.

Cone beam computed tomography (CBCT) as a diagnostic imaging modality has previously been used to determine root canal configurations[12,30–36] This technology has been shown to be as effective in detecting root canals as clinical troughing and scouting under magnification.[29]

A literature search of both the PubMed and Google Scholar databases found no studies regarding the root number and/or canal configurations of first or second mandibular molars in a South African population. Search terms included “lower molar anatomy” and “South Africa”. A PubMed search for the terms “middle mesial canal” and “South Africa” similarly produced no results. A Google Scholar search for the phrases mentioned above yielded two case studies reporting the presence of middle mesial canals in South African individuals. [37,38]

The root and canal anatomy of mandibular molar teeth - including the prevalence of middle mesial canals - in the South African population is unknown.

The present study aimed to describe the root and root canal configurations of first and second mandibular molars in a South African sub-population, with a specific emphasis on the prevalence of middle mesial canals.

1.2 Literature review

1.2.1 Definitions

1.2.1.1 A South African sub-population

Patients who attended the Pretoria Oral and Dental Hospital for a variety of reasons and underwent CBCT scans as part of their dental treatment, diagnosis and treatment planning.

1.2.1.2 Root canal treatment

A dental procedure involving the treatment of an inflamed and/or infected pulp whereby affected pulp tissue is removed from the root canal system and the resultant spaces are shaped, cleaned and filled.

1.2.1.3 Radix entomolaris

An additional root positioned lingual to the mesial and/or distal roots normally found in a lower permanent molar.

1.2.1.4 Radix paramolaris

An additional root positioned buccal to the mesial and/or distal roots normally found in a lower permanent molar.

1.2.1.5 Middle mesial canal

An additional root canal in the mesial root of a mandibular molar tooth, situated between the mesiolingual and mesiobuccal canals.

1.2.1.6 Middle distal canal

An additional root canal in the distal root of a mandibular molar tooth, situated between the distolingual and distobuccal canals.

1.2.1.7 Voxels

Three-dimensional stacked pixels of which a CBCT scan is comprised.

1.2.1.8 C-Shaped canal system

A ribbon shaped canal system connecting possible individual canals, often presenting in the shape of the letter “C” when viewed in an axial plane.

1.2.2 Objectives and principles of endodontic treatment

The three main objectives of endodontic treatment are: to remove inflamed and/or infected dental pulp tissue from the affected tooth; to chemically clean the root canal system of micro-organisms and to fill the resultant space with an obturation material.[39] The desired outcomes of endodontic treatment are firstly the resolution of any clinical signs and/or symptoms of inflammation, infection and/or pathology and secondly for signs of healing to be observed in the adjacent periodontium.[39]

The first principle of endodontic treatment is mechanical cleaning and shaping of the entire root canal from the root canal orifice to the apical constriction.[39] This is accomplished using endodontic files.[39] Individual root canals are enlarged to various apical diameters and tapers. The ideal diameter and taper that will facilitate optimal chemical disinfection of the root canal system is unique to each canal.[40] These variables are determined by the dimensions that facilitate chemical irrigation of the entire root canal system to achieve disinfection efficiently.[40]

A root canal system is comprised of: the main root canal/s, apical deltas, fins, communications, isthmuses, accessory canals and lateral canals.[41]

Chemical disinfection is performed during and after mechanical preparation with a combination of irrigants that remove organic and inorganic debris. The common irrigants used are: sodium hypochlorite to remove organic material, and ethylenediaminetetraacetic acid (EDTA) to remove inorganic debris of the smear layer.[40]

Following mechanical shaping and chemical cleaning, the endodontically prepared intra-canal spaces of a root canal are filled with gutta percha and endodontic sealer.[42] This creates an apical seal to prevent reinfection of the root canal system and to facilitate healing of the periodontium.[42]

Hegde and Singh[43] suggested that the principles of sound endodontic treatment are similar to any surgical procedure. These principles are described as follows:

1) Practicing aseptic techniques – isolation of the working field and the use of sterilized instruments;

2) Root canal debridement – mechanical preparation;

3) Draining exudate from purulent lesions;

4) Chemoprophylaxis – endodontic irrigants and intracanal medicaments;

5) Immobilization – occlusal reduction to decrease (masticatory) forces if necessary;

6) Minimal trauma to adjacent tissues during treatment.

1.2.3 Successful endodontic therapy

The criteria used to define success of endodontic therapy is inconsistent in the reported literature.[44] Various factors have been used as guidelines to determine when root canal treatment should be considered successful. The factors most commonly considered are the absence of clinical signs and symptoms and evidence of radiographic healing.[45–48] Radiographic healing refers to the absence of radiographic signs of pathology in the adjacent periapical and/or periradicular tissues,[49] a reduction in the size of radiographic lesions over time[50] and a normal appearance of the periodontal ligament space.[51]

Although bony repair of the periapical and/or periradicular bone is considered to be ideal healing, fibrous repair may also be considered an acceptable outcome.[52] Clinical evidence of healing is an important consideration as radiographic findings alone have been found to be unreliable to assess the outcome of endodontic therapy.[52]

Endodontic treatment failure, as with success, has inconsistent definitions in the literature. Common signs attributed to failed endodontic treatment include recurring or persistent pain,[28] non-healing sinus tracts and/or swollen periodontium.[42]

Endodontic failure may be the result of the following: inadequate debridement and irrigation with persistent bacteria,[28] overfilling beyond the apical constriction;

inadequate coronal seal;[28] poor or short apical seal;[42] missed canals;[46] and adverse iatrogenic events such as separated instruments and perforations. [46]

1.2.4 Endodontic failure related to missed root canals

It is well known that additional internal anatomy may present in the human dentition. Additional internal anatomy has been reported in the following tooth types: upper second premolars;[2–5] lower central incisors;[6,7] lower lateral incisors;[8,9] upper first molars;[10–13] and upper second molars.[11,12,14]

Successful root canal treatment relies upon adequate access, cleaning, shaping and sealing of the entire root canal system.[28] Missed (i.e. untreated) root canals are considered to be one of the major causes of unsuccessful endodontic treatment.[46] The consequences of missed anatomy during root canal treatment may include the need for additional, and potentially more invasive dental intervention.[53]

The first-line treatment approach for cases where primary endodontic treatment has failed is non-surgical endodontic retreatment.[53] If non-surgical endodontic retreatment is either impractical, impossible or this repeated orthograde approach is unsuccessful, surgical procedures may be needed to eliminate the residual pathology.[54]

One study of endodontic treatment undertaken at a dental school in the United States of America[54] reported that eight percent of failed treatments were associated with missed root canals. Another study[55] demonstrated 42% (n = 143/337) of all non-surgical endodontic retreatments were required due to missed anatomy during primary endodontic treatment. In 2011 Song *et al.* reported 19.7% of failed primary endodontic treatment could be was attributed to missed root canals.[56]

1.2.5 Endodontic success rates

In 1956, Strindberg reported root canal treatment to be successful in 93% of teeth which presented without periapical periodontitis and 80% in teeth with periapical periodontitis. [57]

More recently, Friedman and Mor[58] evaluated endodontic success rates as reported over a 40-year period. It was determined that endodontic success rates remained relatively stable when adjusted for case selection and measurement of outcomes.[58] This is a remarkable finding considering how the equipment, instruments and materials used to perform root canal therapy have changed in the modern era. A 2018 study regarding endodontic success rates found 97% success in vital teeth and 87% in non-vital teeth.[59]

An epidemiological study including over 1,4 million teeth reported a success rate of 97% over an eight year period for endodontic treatments performed by both general dental practitioners and specialist endodontists.[60] Most failed cases were observed to present within the first three years and 85% of these failures were due to a lack of full coronal coverage.[60]

1.2.6 Detecting root canals using cone beam computed tomography

Root canal configuration studies have been performed using a variety of different techniques and methodologies. Previously reported methods include the following: standard radiography;[61] plastic casts;[62] clearing and staining;[25] clinical troughing;[29] CBCT;[61] and micro computed tomography.[63]

Cone beam computed tomography (CBCT) is a three-dimensional diagnostic imaging modality which has been successfully applied to several disciplines in dentistry.[64] The use of CBCT offers several advantages to facilitate the present study. These advantages include: the existence of a large patient database for retrospective study, a non-invasive means of data acquisition and an accurate representation of the dental anatomy on living subjects.

The application of CBCT has been shown to be beneficial for the clinical treatment of endodontic patients. In addition to accurate determination of root anatomy and root canal configurations, the methodology may be used in the diagnosis of cysts, determination of the extent of periapical lesions, identification of internal and external resorption, detection of root fractures and the visualisation of perforations and separated instruments.[64]

A CBCT scan is composed of pixels which are stacked in three dimensions.[52] Such three-dimensional pixels are referred to as voxels.[52] Voxel sizes may differ, with reported ranges from as small as 0.076mm to as large as 0.6mm.[52] Due to the relatively small voxel size, CBCT images show better detail for the examination hard tissues as compared to scans from routine medical computed tomography.[52] The smaller the voxel size, the finer the detail on the resultant CBCT scan will be. The maximum effective CBCT voxel size for endodontic purposes is reportedly 0.2mm.[52]

The variation of voxel sizes previously reported in the literature is too broad to establish a general protocol for the ideal voxel size to be used in endodontic studies.[65] It has been recommended that although smaller voxel sizes result in greater image detail, larger voxel sizes may be acceptable on a case-by-case basis.[65]

Several authors have previously used CBCT to describe root anatomy and canal configurations.[12,30–34] Cone beam computed tomography has been shown to be as accurate as the clearing and staining technique and been proven to be better than two-dimensional periapical radiography in determining root anatomy and canal configurations.[61]

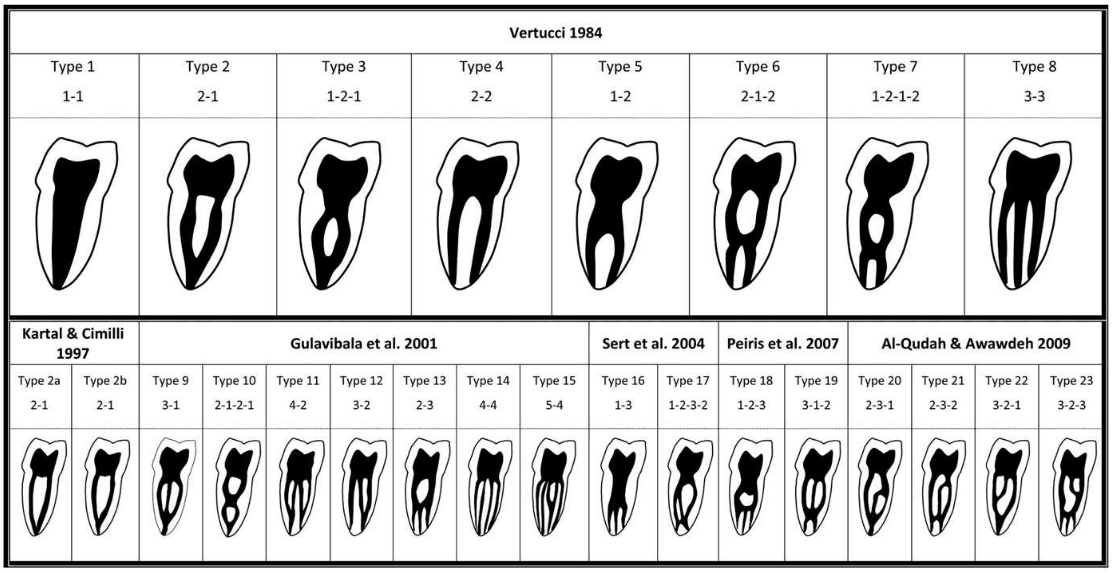
1.2.7 Classification of root canals

Several different classification systems have been used to describe root canal anatomy.

Weine *et al.* described the first root canal classification system in 1969, which consisted of only four canal types.[23] Fifteen years later, Vertucci described an expanded classification including eight types 15.[1] Kartal *et al.* created two additions[66] and one modification[67] to the Vertucci system in 1992 and 1997 respectively. Gulabivala *et al.* added seven new types to the Vertucci system in 2001,[68] followed shortly thereafter by Sert and Bayirli's additions[25] in 2004.

A graphic representation of the expanded Vertucci classification systems can be seen in Figure 1.

Figure 1: Classification systems as illustrated by De Pablo *et al.*[69]



The most commonly used root canal classification system is the Vertucci classification.[24] The original Vertucci classification consisted of eight root canal configurations[1] as seen illustrated in Figure 2 below.[70]

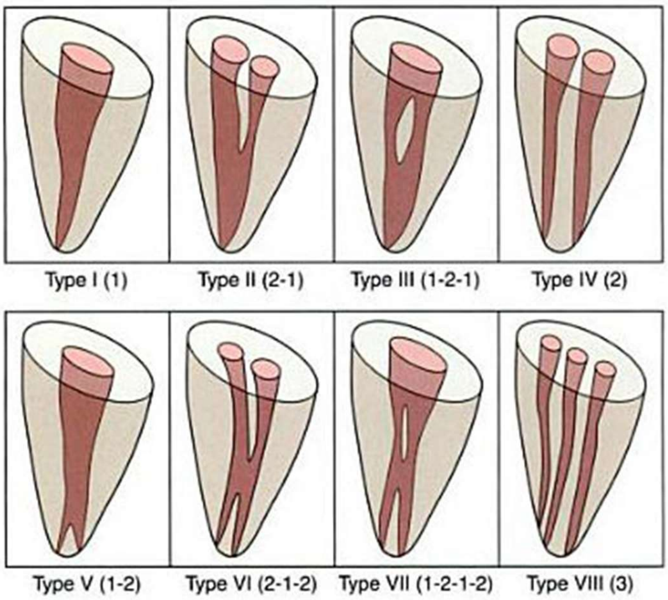


Figure 2: Vertucci canal classification system[70]

In 2004 Sert and Bayirli added 15 additional variations to Vertucci's original classification. These additions primarily relate to the possibility of three or more canals.[25]The additions of Sert and Bayirli are demonstrated in Figure 3.[70]

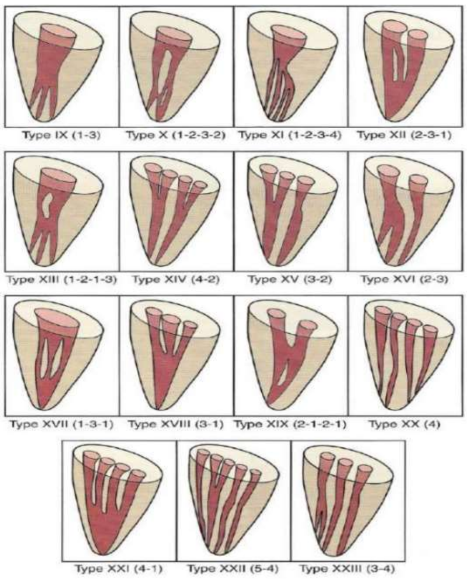


Figure 3: Sert and Bayirli's additions to the Vertucci system[70]

The resultant 23 different morphological root canal variations can be applied easily to describe the root canal configurations found in the roots of lower molars.[51]

The classification system may be summarised as follows:

- Type I describes a simple one canal system, consisting of one orifice, a single canal and one apical foramina;

- From Type II to Type VII the possible variations of two canal systems are described; Type II features two orifices with two canals that exits at one apical foramina, Type III features one orifice and one foramina with two canals in the mid-root area, Type IV has two orifices, two separate canals throughout the whole root system and two foramen, Type V presents with one orifice which splits into two canals and two portals of exit, Type VI displays two orifices and two foramina which fuses in a mid-root communication. Type VII presents in a similar fashion to Type VI but with a singular orifice.

- From Type VIII to Type XVIII all possible variations of the three to four canal systems are described; Type VIII features three separate orifices, canals and apical foramen for the entirety of the root, Type IX presents with one orifice which split into three canals and portals of exit, Type X has one orifice from which two canals split off, mid-root the one canal further splits in two canals to become a total of three canals that fuses at the apical foramen with the same canal to result in the original two canals exiting from their own portals of exit. Type XI has one orifice which split into two canals which split further into first three and then a total of four canals, each with their own portals of exit. Type XII features two orifices with two canals and one singular foramen, mid-root there is a third canal connecting the two canals obliquely. Type XIII presents with one foramen which splits into two canals and fuse into one, after which it splits into three canals each with their own portal of exit. Type XIV has four orifices of which each pair fuses into one canal to result in two canals each with their own portals of exit. Type XV has three orifices and three canals that fuse into two canals that exit out of two foramina. Type XVI canal configurations has two orifices of which one canal splits into two canals to result in a total of three canals each with their own foramen. Type XVII features one orifice and one foramen with three canals mid-root. Type XVIII three orifices and three canals which fuse into one canal and foramen.

- The sole Type XIX classification describes a two-canal system with two orifices and a singular foramen as well as a mid-root communication/fusion of the two canals.

- And lastly the root canal configurations designated from Types XX to XXIII, are root canal variations with four and five canal systems; Type XX present with four separate canals through the whole root, Type XXI has four orifices and canals but fuse into one foramen and portal of exit, Type XXII has five orifices with two of the canals fusing to form four canals with four foramina, Type XXIII features three orifices and canals with one canal splitting and resulting in four canals and four portals of exits.

The Vertucci classification with the additions of Sert and Bayirli have previously been used to describe the root and canal anatomy in Turkish, Iranian and Greek sub-populations.[25–27]

1.2.8 Classification of the number of roots

Mandibular molars may present with either one, two, three or four roots.[71] A one rooted molar can have either a single conical root or a fused root; a two rooted molar has one mesial root and one distal root; a three rooted molar can have a mesial and distal root with either an additional root placed distolingual (radix entomolaris), distobuccal (radix paramolaris) or mesial; and a four rooted molar may present with two distal roots and two mesial roots.[71]

C-shaped roots also exist; however, these teeth are described using a unique classification system.[72] For the purposes of the present study, C-shaped roots were not classified or described, but merely noted.

1.2.9 Previous data on lower molar root and canal morphology

1.2.9.1 Root morphology of mandibular first and second molars.

The most common root morphology of human mandibular molars is two separate roots, namely one mesial and one distal root respectively.[73,74]

A study by Gulabivala *et al.*[68] reported the prevalence of a single conical root to be 14.9% in mandibular second molars. No single rooted mandibular first molars were reported.

Two previous studies, the first by Ferraz and Pecora[75] and the second by Gulabivala *et al.*[68] reported the prevalence of three-rooted mandibular molars (radix entomolaris or radix paramolaris) to range between five to ten percent in participants of Mongoloid descent.

Studies by Ferraz and Pecora,[75] and Steelman[76] reported the incidence of a third root in mandibular molars in Brazilian subjects of European descent to be lower - 6.8 and 6.4% respectively - than the incidence among individuals of African descent (7.5%).

Only one study[77] and four case reports[78–82] regarding four-rooted mandibular molars could be found. A study reporting root number of an Israeli sub-population revealed the incidence of four rooted mandibular molars to be only 0.55% in mandibular second molars and zero in mandibular first molars.[77]

1.2.9.2 Root canal morphology of mandibular first and second molars.

Mandibular first molars

De Pablo *et al.*[69] (2010) demonstrated the most common canal configuration in the mesial roots of mandibular first molars to be Vertucci Type IV, followed by Type II. The most common canal type in the distal roots of mandibular first molars was Type I with a prevalence of 63%.

Gulabivala *et al.*[68] (2001) reported the most prevalent canal configuration in the mesial roots mandibular first molar to be Type II, followed by Type IV. The distal canals of the mandibular first molars were reported to have an 81% incidence of Type I canal configurations.

In a separate study undertaken one year later Gulabivala *et al.*[83] (2002) reported the most common canal types in mandibular first molars to be Type IV canals in the mesial roots (67%) and Type I canals for distal roots (80%).

Mandibular second molars

In the Gulabivala *et al.*[68] (2001) study, it was found that second mandibular molars demonstrated similar prevalence of the configurations observed in mandibular first molars: 90% of the canals in the distal root being Type I and a combined incidence of Type II and Type IV in 63% canal systems in the mesial root.

The findings of the Gulabivala *et al.*[83] (2002) study found similar results in mandibular second molars; 70% presented with Type I canals in the distal root and 57% with Type IV canals in the mesial root.

1.2.9.2.1 Middle mesial canals of mandibular molars

1.2.9.2.1.1 Prevalence of middle mesial canals

A literature search regarding the prevalence of middle mesial canals in mandibular first and second molars (using several different methodologies) revealed a variety of results.

Several studies have reported combined results for the prevalence of middle mesial canals in first and second mandibular molars,[35,84-85] whilst others have reported on the prevalence in mandibular first molars exclusively.[63,66,69,81-82] Of the studies which reported combined results, the prevalence ranged from 16% in 2017,[35] 20% in 2015,[84] up to 46% in 2015.[85]

A review of the published literature from 1971 to 2010 reported the prevalence of middle mesial canals in both first and second mandibular molars (combined) to vary between zero percent to 21.7% across 17 studies. [86]

The studies which reported on the prevalence of middle mesial canals in mandibular first molars exclusively reported a prevalence range of 12%[63] in 2014, up to 28%[87] in 2016.

A review of literature from the year 1900 to 2010 by Ballullaya *et al.,*[88] reported a prevalence of 0.95 - 15% for middle mesial canals in mandibular first molars.

1.2.9.2.1.2 Effect of age on the detection of middle mesial canals

Azim *et al.* reported middle mesial canals to be present in 46.2% of mandibular molars. A higher prevalence was found in mandibular second molars as compared to first molars. Younger patients displayed a statistically significant higher prevalence of middle mesial canals as compared with older patients.[85]

In agreement with these findings Nosrat *et al.*[84] reported that in patients younger than 20 years of age nearly one-third of mandibular molars presented with middle mesial canals. Almost one-quarter of patients in the age group 21 to 40 years, and 3.8% in patients older than 40 years also had this additional mesial canal.

1.2.9.2.1.3 Configurations of middle mesial canals

Previous studies have described the classification of middle mesial canals into broad characteristics, such as being independent, confluent or fin-like. The following studies regarding the configuration of middle mesial root canals of mandibular lower molars have been found:

Nosrat *et al.* (2015) reported that just under half of middle mesial canals presented as confluent canals and only one-fifth were independent canals.[84]

Sherwani *et al.* (2016) found a high prevalence of middle mesial canals (28%). Confluent canals were described in 75%, fin anatomy in 22% and independent canals in less than three percent of cases.[87]

Arayasantiparb *et al.* (2017) found the prevalence rate of middle mesial canals to be low at 0.22%. Half the canals were described as independent and the other half were described as confluent canals.[30]

No studies regarding either the prevalence or configuration of middle mesial canals in mandibular first or second molars of a South African population could be found.

1.2.9.2.2 Distal canals of mandibular molars

De Pablo *et al.*[69] found that between 1971 - 2010 the most common root canal configuration for distal roots in mandibular first molars was Type I (62.7%), followed by Type II (14.5%) and Type IV (12.4%).

In addition to the above-mentioned studies Goel *et al.,*[89] (1991) reported distal roots to have one canal 58.3% of the time, two canals 40% and three canals in only 1.7% of cases. Neelakantan *et al.*[74] (2010) observed a prevalence of a third distal canal in only 0.57% in an Indian population. Filpo-Perez *et al*.[90] (2015) demonstrated the majority of distal roots in mandibular first molars have a singular canal (76%) and the presence of three or four canals in 11% of the evaluated sample.

1.2.9.3 C-shaped root and canal morphology in mandibular molars

The literature reveals the prevalence of C-shaped canals in a Brazilian population to be 1.7% in mandibular first molars and 3.5% in mandibular second molars.[31]

A Sri Lankan population demonstrated C-shaped roots to be prevalent in six percent and C-shaped canals in up to two percent of mandibular second molars.[91]

A 7.5% prevalence of C-shaped canal systems in the mandibular second molars was found in an Indian population.[74]

C-shaped roots were reported in ten percent of a Sudanese sample of second molars[71] as well as in a Jordanian population (first and second mandibular molars combined).[92]

A Thai population of mandibular second molars,[83] and Burmese population were found to have C-shaped root and canal systems in 22.4% of mandibular second molars[68] A Chinese population presented with a prevalence of C-shaped roots and canals in mandibular second molars to be as high as 31,5%.[93]

The prevalence of C-shaped canal systems has been found to be higher in certain Asian populations as demonstrated by the above-mentioned studies.

No previous South African studies regarding the prevalence of C-shaped roots or canal systems in mandibular molars could be found. A more detailed description of this anatomical variation is beyond the scope of this text.

CHAPTER 2: AIMS AND OBJECTIVES

2.1 Aims

The aim of the present study was to classify the root number and the root canal configurations of human mandibular first and second molars in a defined population of patients attending the Pretoria Oral and Dental Hospital, using CBCT.

2.2 Objectives

The objectives of this study were to:

1) Document the prevalence of C-shaped root and canal systems observed in this sample of mandibular first and second molars (without specifying the exact classification of the C-shaped canals);

2) Classify the root number of the mandibular first and second molars (1-2-3-4) for this sample;

3) Classify the root canal configurations of each root of the mandibular first and second molars (Type I-XXIII) for this sample;

4) Report the prevalence of middle mesial root canals observed in this sample;

5) Correlate the prevalence of root canal configurations to the sex and/or age of the participants in this sample.

2.3 Null hypothesis

There are no significant differences regarding root number and canal configurations if the variables of sex and age are tested.

No significant differences would be found in the proportion of middle mesial and middle distal canals present in a South African sub-population between first and second mandibular molars and previously studied population groups.

CHAPTER 3: MATERIALS AND METHODS

3.1 Methods overview and basis

The study design was a retrospective cross-sectional descriptive study. The sampling method used was convenience sampling and CBCT scans were retrospectively evaluated from the most recently acquired scans until the necessary sample size was achieved.

For the purposes of the present study the root number of the mandibular first and second molars were classified into either one, two, three or four rooted. Specific reporting related to the presence of radix entomolaris, radix paramolaris and the presence of two mesial roots was made. The mesial and distal root canal systems were classified using the Vertucci[1] classification system, including the additional modifications described by Sert and Bayirli.[25]

Evaluation of the CBCT images in the present study was based on the methodology previously described in the studies of Betancourt *et al.,*[14] Nur *et al.,*[34] and Wang *et al.*[32] - with modifications.

The Betancourt *et al.*[14] study was performed on mesiobuccal root of the maxillary first and second molars. The Nur *et al.*[34] and Wang *et al.*[32] studies were performed using CBCT on lower molars but did not use the additions of Sert and Bayirli. The Sert and Bayirli additions in conjunction with the Vertucci classification were used in studies by Sert and Bayirli,[25] Rezaeian *et al.*,[26] and Kantilieraki *et al.*[27]

The exact methodology used in this study is described in the following sections.

3.2 Source of CBCT scans for analysis

All the CBCT scans evaluated for the present study were taken at the Division of Oral Radiology (Department of Oral Pathology and Oral Biology) at the Oral and Dental Hospital, University of Pretoria (CBCT unit: Planmeca Promax 3D Max, Planmeca Oy, Helsinki, Finland). The CBCT-scans of patients referred from the various Departments of the School of Dentistry as well as from private dental practitioners were included. The scans used in this study were acquired for several reasons, including, but not strictly limited to: the diagnosis of maxillo-facial trauma and surgery; orthodontic, endodontic and implant treatment planning.

Only scans on the existing database were used from which to retrospectively draw the study samples from. No new CBCT scans were acquired for the purposes of this study.

CBCT scans of mandibular first and second molars in the existing CBCT database of the Division of Radiology were included, starting with the most recently taken scans and working chronologically in decreasing order, until the sample size was achieved. The time period ranged from September 2016 to November 2018.

3.3 Analysis of the CBCT scans

The CBCT images of each individual mandibular first and second molar were evaluated in coronal, sagittal and axial views by two previously calibrated examiners with experience in endodontics by scrolling through the slices from coronal to apical, distal to mesial, and buccal to lingual. Examiner calibration was performed by evaluating a set of 20 CBCT scans together prior to conducting the study. This was done in order to establish consistency of the evaluations.

During evaluation of the scans, the viewing plane was set to the level of the pulpal floor and the slices set to the smallest increments and each slice clicked through individually until the apex was reached. The same steps were followed in a distal to mesial direction with the viewing plane set approximately perpendicular to the root being evaluated and starting at the distal most aspect of the root scrolling through to the most mesial aspect of the root. Finally, the same steps were followed in a buccal to lingual direction with the viewing plane set parallel to the long axis of the tooth being examined. The examiners evaluated each sample independent of one another.

3.4 Classification of the root number and root canal configurations of the mandibular molars

Classification of the canal configurations of each root was made using the Vertucci classification system, including the modifications proposed by Sert and Bayirli (Figure 4).

As previously described by Tian *et al.*,[152] two examiners classified each sample independently. Following classification of all samples the examiners findings were compared. In cases of agreement the classification was accepted. In the event of disagreements regarding classification type, the samples were re-evaluated by a third examiner, with experienced in both endodontics and the interpretation of CBCT imaging to determine a final classification.

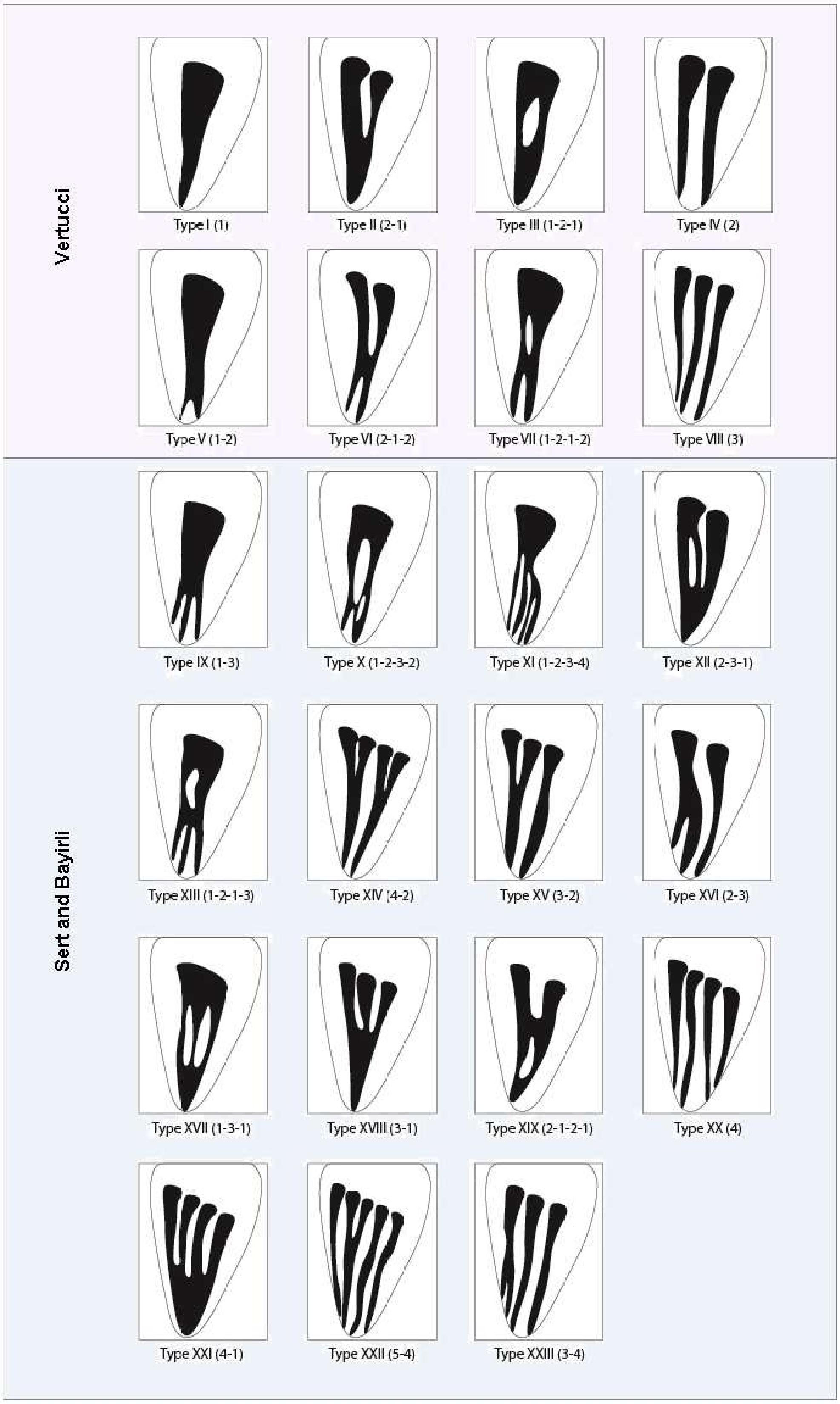


Figure 4: Vertucci classification system with the additions of Sert and Bayirli

3.5 Additional information collected

During data collection the patient's sex and age at the time of acquisition of the scan and the sex of the subjects were recorded to allow evaluation of a possible age and/or sex links to canal classifications. The voxel size was also noted.

Subjects were divided into three age categories as follows: younger than 25 years, 25 to 40 years, older than 40 years. This is in line with the methodology previously described by Nosrat *et al.*[84]

3.6 Inclusion criteria

For inclusion, a scan had to contain a minimum of either one mandibular first or second molar. Included teeth must have displayed roots that were fully formed and the root canal orifices and radicular root canal system visible on the scan.

3.7 Exclusion criteria

The following factors eliminated a mandibular first or second molar from being included in this study: root canal orifices not clearly visible on the CBCT scan or the entire radicular root canal system/s not included in the scanned area (including previous apicectomy making accurate determination impossible); the presence of radicular posts, large restorations, metal fixtures or implants in close proximity to the roots (this may have produced scatter making interpretation unreliable); total canal calcifications/obliterations which obscured the original number of root canals; severe root resorption rendering interpretation unreliable; conical teeth and C-shaped teeth with no clear separate mesial and distal canal systems were excluded from root canal classification (but not from root number analysis).

Scans with voxel sizes above 200 were excluded from the study during the process of data collection, as these scans were found to display too little detail to allow accurate classification of the canal systems.

Any examiner was permitted to exclude a scan if the image quality was deemed too poor for accurate evaluation.

All teeth other than mandibular first and second molars were excluded from this study.

3.8 Sample size

Sample size was based on an estimation of the prevalence of middle mesial root canals in mandibular first and second molars. It was calculated that with a sample size of at least 753 teeth, a two-sided 95% confidence interval for the prevalence of middle mesial root canals would be within approximately one percent of the prevalence that could be calculated from the sample, assuming a total prevalence of two percent. Sample size calculation was performed using nQuery Advanced (Statistical Solutions Ltd, Cork, Ireland), Release 8.0.0.0, and was based on the large sample normal approximation of the binomial distribution.

It was determined that a minimum of 189 (assuming four teeth per scan were available) and a maximum of 753 scans (if only one tooth per scan was available) meeting the inclusion and exclusion criteria would be required to fulfil the minimum sample size of 753 teeth.

3.9 Data sheet used to capture information

The data capture sheet used in the present study can be seen in Appendix A.

3.10 Statistical analysis

The data was captured using Microsoft Excel 2003. Statistical analysis was performed using SAS v9.4 software (SAS Institute Inc., Carey, NC, USA). The number of roots and canal configurations, classified according the Vertucci classification system with additions by Sert and Bayirli, were expressed as percentages of the total number of molars. Categorical variables were compared with a significance set at $P < 0.05$ using the Chi-squared and Fisher Exact tests.

3.11 Ethical clearance

This research proposal for this study was submitted to the Research Committee of the School of Dentistry (RESCOM), Faculty of Health Sciences, University of Pretoria as well as the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria. Both RESCOM and ethical approval were obtained before the research commenced (Protocol number: 397/2018).

As only existing scans from the CBCT database were retrospectively evaluated, no new patients were exposed to any radiation for the purposes of this research.

CHAPTER 4: RESULTS

4.1 Sample description

A total of 790 mandibular first and second molars were evaluated from the CBCT scans of 300 patients. Thirty-seven molars were found to have either conical roots (n = 3/790, 0.4%) or C-shaped roots with C-shaped canals (n = 34/790, 4.3%). These teeth were excluded from further analysis. A final sample size of 753 remained for evaluation of root and canal configurations.

Of the remaining sample of 753 molars 369 (49%) were mandibular first molars and 384 (51%) were mandibular second molars; 381 (51% were molars on the left side (third quadrant) and 372 (49% were molars on the right side (fourth quadrant).

Of the 300 scans 166 (55%) were from females and 134 (45%) were from males; 74 (25%) were from individuals under the age of 25 years, 103 (34%) were between 25 and 40 years of age, and 123 (41%) were over 40 years of age.

4.1.1 C-shaped anatomy by tooth type

Mandibular second molars (7.7%, n = 32/418) demonstrated a significantly higher chance of presenting with C-shaped anatomy ($P < 0.0001$) as compared to mandibular first molars (0.5%, n = 2/371).

4.2 Classification of root number

Root number classification demonstrated the majority of both mandibular first and second molars had two roots. Two-rooted molars were present in 98.7% (n

= 364/369) of mandibular first molars and 94% (n = 362/384) of mandibular second molars.

One-rooted molars were present in 2.6% (n = 10/384) of mandibular second molars and 0.3% (n = 1/369) in mandibular first molars. Three-rooted molars were observed in 2.9% (n = 11/384) of mandibular second molars and one percent (n = 4/369) of mandibular first molars. Four-rooted molars were present in 0.5% (n = 2/384) of mandibular second molars and absent in mandibular first molars (n = 0/369).

Of the total number of three-rooted molars (n = 15), radix entomolaris was found in six samples (40%, n = 6/15), radix paramolaris was found in one sample (7%, n = 1/15), and eight samples were found to have two mesial roots (53%, n = 8/15).

Only two four rooted molars were observed in second molars, representing 0.5% (n = 2/384) of this group. None of the first molars (n = 0/369) had four roots.

The two four-rooted molars presented with two mesial roots and two distal roots.

4.3 Canal classifications

4.3.1 Vertucci classification, including Sert and Bayirli additions

The canal configurations, classified according to the Vertucci classification system, including the additions proposed by Sert & Bayirli are summarised in Table 1.

Table 1. Prevalence of canal configurations as described by Vertucci, including the additions proposed by Sert and Bayirli (2004) of first and second mandibular molars, described per root.

Classification	First molar mesial % (n)	First molar distal % (n)	Second molar mesial % (n)	Second molar distal % (n)
I	0.54 (2)	50.41 (186)	2.34 (9)	81.25 (312)
II	21.14 (78)	3.52 (13)	24.22 (93)	0.52 (2)
III	1.90 (7)	12.47(46)	7.55 (29)	4.69 (18)
IV	50.14 (185)	5.15 (19)	38.28 (147)	0.52 (2)
V	2.17 (8)	19.78 (73)	7.29 (28)	10.42 (40)
VI	2.71 (10)	0.27 (1)	3.13 (12)	0.26 (1)
VII	0.54 (2)	0.81 (3)	0.26 (1)	0.78 (3)
VIII	1.36 (5)	-	1.30 (5)	-
IX	-	0.54 (2)	0.52 (2)	0.78 (3)
X	3.79 (14)	0.54 (2)	2.34 (9)	-
XI	-	0.27 (1)	-	-
XII	3.79 (14)	0.54 (2)	2.60 (10)	-
XIII	-	0.27 (1)	-	-
XIV	-	-	-	-
XV	7.86 (29)	0.81 (3)	3.91 (15)	-
XVI	1.08 (4)	1.08 (4)	1.04 (4)	0.26 (1)
XVII	-	2.98 (11)	1.30 (5)	0.26 (1)

XVIII	2.17 (8)	0.27 (1)	3.13 (12)	0.26 (1)
XIX	-	0.27 (1)	0.52 (2)	-
XX	0.27 (1)	-	-	-
XXI	0.54 (2)	-	0.26 (1)	-
XXII	-	-	-	-
XXIII	-	-	-	-

The present study found the most common classification of the mesial roots of both mandibular first and second molars to be Type IV (two separate canals) followed by Type II (two canals with separate orifices fusing into one canal and one portal of exit). It was found that in both mandibular first and second molars the distal root most often presented with a Type I configuration (one single canal), followed by the Type V configuration (two canals with one orifice splitting into two canals each with their own portal of exit).

Types XIV, XXII and XXIII were not represented in any of the mandibular first or second molars.

4.3.2 Canal classifications grouped by canal number

Canal classifications were separated into four groups depending on the highest number of canals present in the canal system as can be seen in Table 2 below.

Table 2. Canal group classifications

Groups	Number of canals	Classifications included in this group
Group 1	One	I
Group 2	Two	II, III, IV, V, VI, VII, XIX
Group 3	Three	VIII, IX, X, XII, XIII, XV, XVI, XVII, XVIII
Group 4	Four or more	XI, XIV, XX, XXI, XXII, XXIII

4.3.2.1 Mandibular first molars classified by group

Most mesial roots of the mandibular first molars in the present study demonstrated two canals (78.6%, n = 290/369). The second most common canal number in the mesial roots was three canals (20.1%, n = 74/369). The least common canal numbers were four or more canals (0.8%, n = 3/369) or one canal (0.5%, n = 2/369).

Just over half (50.4%, n = 186/369) of the distal roots of the first mandibular molars included in the present study were found to have one canal. Two canals were found to be the second most common root canal number for this root at 42.28% (n = 156/369). The prevalence of three canals was considerably lower in the distal roots of the first mandibular molars than the mesial roots at 7.05% (n = 26/369). Four or more canals were only found in one (0.27%) of the distal roots of the first mandibular molars included in the present study. The results of mandibular first molars classified by group is demonstrated in Table 3 below.

Table 3. Mandibular first molars: canal number groups

Group	Mesial root % (n)	Distal root % (n)
1	0.5 (2)	50.4 (186)
2	78.6 (290)	42.3 (156)
3	20 (74)	7 (26)
4	0.8 (3)	0.3 (1)

4.3.2.2 Mandibular second molars classified by group

The mesial roots of the mandibular second molars included in this study most commonly demonstrated two canals (81.25%, n = 312/384). One canal was present in 2.34% (n = 9/384) of the second molars, three canals in 16.15% (n = 62/384), and four or more canals in 0.26% (n = 1/384) of the time.

The distal roots of second mandibular molars included in the present study most commonly had one canal (81.25%, n = 312/384). Two canals were identified in 17.19% (n = 66/384) of these distal roots. Only six (1.56%) of these roots demonstrated three canals. None of the distal roots of the mandibular second molars in this study had four or more root canals. The results of the mandibular second molars grouped by canal number can be seen in Table 4 below.

Table 4. Mandibular second molars: canal number groups

Groups	Mesial root % (n)	Distal root % (n)
1	2.3 (9)	81.3 (312)
2	81.3 (312)	17.2 (66)
3	16.2 (62)	1.6 (6)
4	0.3 (1)	0 (0)

The combined number of canals for both first and second mandibular molars per mesial and distal root is summarised in the Table 5 and comparative number of canals are summarised in Table 6.

Table 5. Mandibular first and second molars combined: canal number groups

Groups	Mesial roots % (n)	Distal roots % (n)
1	1.46 (11)	66.14 (498)
2	79.95 (602)	29.48 (222)
3	18.06 (136)	4.25 (32)
4	0.53 (4)	0.13 (1)

Table 6. Canal number groups of mandibular first and second molars per root.

Groups	First molar mesial (n)	First molar distal (n)	Second molar mesial (n)	Second molar distal (n)
1	0.5% (2)	50.4% (186)	2.3% (9)	81.3% (312)
2	78.6% (290)	42.3% (156)	81.3% (312)	17.2% (66)
3	20% (74)	7% (26)	16.2% (62)	1.6% (6)
4	0.8% (3)	0.3% (1)	0.3% (1)	0% (0)

A single canal was significantly more likely to be found in the distal root of the mandibular second molars compared to the first molars. ($P < 0.05$) A two canal system was significantly more likely to be found in the distal root of the mandibular first molar compared to the second molar. ($P < 0.05$)

A third canal was significantly more likely to be present in the distal root of the mandibular first molar as compared to the mandibular second molar ($P = 0.0002$).

Similarly, a third canal was found more often in the mesial root of the mandibular first molar as compared to the mandibular second molar, however this difference was not statistically significant ($P > 0.05$).

Three canal systems were found more often in the mesial roots than the distal roots of the first and second mandibular molars.

4.3.3 Influence of sex on canal configurations

No correlation between canal configurations and sex was observed. ($P > 0.05$)

4.3.4 Influence of age on canal configurations

The canal classifications divided into groups were compared to the age cohorts described in the materials and methods of this study. The results from the canal groups and age groups are demonstrated in Tables 7,8,9 and 10.

Table 7. Canal distribution per age group: Mandibular first molar, mesial root

First molar mesial root			
Group	Younger than 25 years % (n)	25 to 40 years % (n)	Older than 40 years % (n)
1	0.89 (1)	0 (0)	0.84 (1)
2	82.14 (92)	80.43 (111)	73.11 (87)
3	16.96 (19)	18.84 (26)	24.37 (29)
4	0 (0)	0.72 (1)	1.68 (2)

Table 8. Canal distribution per age group: Mandibular first molar distal root

First molar distal root			
Group	Younger than 25 years % (n)	25 to 40 years % (n)	Older than 40 years % (n)
1	54.46 (61)	48.55 (67)	48.74 (58)
2	41.07 (46)	44.20 (61)	41.18 (49)
3	4.46 (5)	6.52 (9)	10.08 (12)
4	0 (0)	0.72 (1)	0 (0)

Table 9. Canal distribution per age group: Mandibular second molar mesial root

Second molar mesial root			
Group	Younger than 25 years % (n)	25 to 40 years % (n)	Older than 40 years % (n)
1	5.26 (5)	2.82 (4)	0 (0)
2	82.11 (78)	79.58 (113)	82.31 (121)
3	12.63 (12)	17.61 (25)	17.01 (25)
4	0 (0)	0 (0)	0.68 (1)

Table 10: Canal distribution per age group: Mandibular second molar distal root

Second molar distal root			
Group	Younger than 25 years % (n)	25 to 40 years % (n)	Older than 40 years % (n)
1	88.42 (84)	77.46 (110)	80.27 (118)
2	9.47 (9)	21.13 (30)	18.37 (27)
3	2.11 (2)	1.41 (2)	1.36 (2)
4	0 (0)	0 (0)	0 (0)

The canal number groups per age group, per root, is summarised in Table 11.

Table 11. All age group data combined

	Below 25 years				25 to 40 years				Over 40 years			
Groups	1st Mesial % (n)	1st Distal % (n)	2nd Mesial % (n)	2nd Distal % (n)	1st Mesial % (n)	1st Distal % (n)	2nd Mesial % (n)	2nd Distal % (n)	1st Mesial % (n)	1st Distal % (n)	2nd Mesial % (n)	2nd Distal % (n)
1	0.89 (1)	54.46 (61)	5.26 (5)	88.42 (84)	0 (0)	48.55 (67)	2.82 (4)	77.46 (110)	0.84 (1)	48.74 (58)	0 (0)	80.27 (118)
2	82.14 (92)	41.07 (46)	82.11 (78)	9.47 (9)	80.43 (111)	44.20 (61)	79.58 (113)	21.13 (30)	73.11 (87)	41.18 (49)	82.31 (121)	18.37 (27)
3	16.96 (19)	4.46 (5)	12.63 (12)	2.11 (2)	18.84 (26)	6.52 (9)	17.61 (25)	1.41 (2)	24.37 (29)	10.08 (12)	17.01 (25)	1.36 (2)
4	0 (0)	0 (0)	0 (0)	0 (0)	0.72 (1)	0.72 (1)	0 (0)	0 (0)	1.68 (2)	0 (0)	0.68 (1)	0 (0)

An apparent tendency for the increased prevalence of third canals with increasing age was noted, however the results were not conclusive.

4.3.5 Voxel size

The majority of scans demonstrated a voxel size of 200 (n = 287/300, 95.6%). Of the 300 scans evaluated, a small number were taken at a voxel size of 100 or 150 (n = 13/300, 4.3%).

CHAPTER 5: DISCUSSION

All dental practitioners providing endodontic treatment must have a detailed understanding of both the common and uncommon root number and root canal morphology of all teeth types, as well as anatomical variations thereof. Knowledge specifically regarding the internal and external morphology of molar teeth is especially important to clinicians performing endodontic treatment, as it has been previously demonstrated that the success rate of endodontic treatment is lower in this tooth type.[94]

No data regarding the root number or canal configurations of mandibular molars in a South African population could be found. This study is therefore the first investigation to report on the root and canal morphology of mandibular molar teeth from the South African geographical region and population group. A literature search revealed only four previously published scientific articles regarding root and root canal configurations of other tooth types in South African populations. One study undertaken on human fossils reported the evolution of the premolar in man.[95] Two publications described the prevalence of the second mesiobuccal canal found in maxillary molars.[96,97] The fourth study determined the root and root canal configurations of maxillary premolars in a South African sub-population.[22]

A failure to locate and treat all canals during root canal treatment may be detrimental to a successful endodontic treatment outcome.[28] Rare or complex variations regarding root number and canal configurations should be routinely taught at dental schools to ensure that future clinicians are aware of these variations and their relative prevalence in a practice setting. The provision of accurate data regarding dental anatomy is therefore essential to ensure the best possible outcome of endodontic treatment. The findings of the present study may be used in the endodontic training curriculum of undergraduate dental students.

The injudicious application of scouting or troughing for possible canals when they are not present may increase the risk of adverse treatment outcomes.

Clinically locating a middle mesial canal often requires a practitioner to trough the isthmus between the mesiolingual and mesiobuccal canals.[98] This is the thinnest area of the mesial mandibular root. Scouting and troughing of this area may lead to extensive removal of healthy tooth structure and an increased risk of perforation.[98] Subjecting a patient to these risks would be unnecessary, and even potentially unethical, if the prevalence of these additional canals is low.[98] The prevalence of middle mesial canals in the present study was 20% for mandibular first molars and 16.2% for mandibular second molars. It is therefore advisable to search for these additional canals.

5.1 Classification system

The Vertucci classification system with additions of Sert and Bayirli was used in the present study due to the system having been widely used in previous research. This allowed for ease of comparison between the results of the present study and previous investigations. The additions by Sert and Bayirli were included to allow for the reporting of third and fourth canals, which are often present in molar teeth. Vertucci's original classification system of only eight configurations was not well suited to the classification of more complex systems containing additional canals.

In 2017, Ahmed *et al.,*[99] proposed a new root canal classification system. [99] This system is highly accurate for the description of precise root and canal anatomy, especially in teeth with complex anatomy. Buchanan *et al.* (2020), recently compared the Vertucci classification system to the system proposed by Ahmed.[22] It was reported from a sample of 601 maxillary premolars that only a very small number of teeth could not be adequately classified using the Vertucci system. The use of Ahmed's newer system in a large study (such as the present study) with many complex configurations would lead to the creation of a high number of different configurations/categories. Using this system would therefore have made meaningful comparison of the results from the present study to previous investigations difficult. For this reason, the Ahmed *et al*. classification system was not considered suitable for use in the present study.

5.2 Root anatomy of human mandibular first and second molars

In the present study, a distribution of one, two, three and four-rooted molars was found. This distribution of root numbers falls within the range of previously reported studies from varying geographical regions as demonstrated in Tables 12 and 13 below.

5.2.1 Mandibular first molar root anatomy

The present study demonstrated a prevalence of 0.3% of one-rooted, 98.7% two-rooted and one percent three-rooted mandibular first molars. These finding corresponded closely to the findings of Nur *et al.* (2014) who also used CBCT. Gulabivala found a higher prevalence of three-rooted mandibular first molars in both a Burmese (2001) and a Thai (2002) population using the clearing and staining technique.

The present study demonstrated a low prevalence of three-rooted first molars, and higher numbers of C-shaped mandibular first molars, than previously studied groups.

Table 12. Reported root number of mandibular first molars

First Molars	Country	One rooted (%)	Two rooted (%)	Three rooted (%)	Four rooted (%)	C-shaped (%)
Gulabivala *et al.* (2001)[68]	Burmese		89.9	10.1		
Gulabivala *et al.* (2002)[83]	Thai	0.6	85.6	9.4	0.6	3.8
Ahmed *et al.* 2007[71]	Sudanese	3	94	3		
Peiris *et al.* (2007)[91]	Sri Lankan		97	3		
Al-Quda& Awawdeh *(*2009)[100]	Jordanian	0	96	4		
Rwenyonyi *et al.* (2009)[101]	Ugandan		100			
Neelakantan *et al. (*2010)[74]	Indian	-	-	-	-	-
Miloglu *et al.* (2013)[33]	Turkish	0	97.6	2.4		
Silva *et al.* (2013)[31]	Brazilian	3	95.3			1.7
Nur *et al.* (2014)[34]	Turkish	0.3	99.2	0.5		
Present study*	South African	0.3	98.7	1		(8.6) *

* C-shaped teeth were excluded from root analysis and only noted as additional data

5.2.2 Mandibular second molar root anatomy

The present study found that mandibular second molars presented with one root 2.6% of the time, two roots 94% of the time, three roots 1.9% of the time, and four roots 0.5% of the time.

One-rooted second mandibular molars were found in similar proportions in a Jordanian sample (2009)[92] and three-rooted second mandibular molars were found in similar proportions in a Thai population (2002).[101]

A new observation from the present study was the existence of four-rooted second mandibular molars.

The prevalence of C-shaped canal systems was comparatively low (0.5%) in the present study compared to the other studies.

Table 13. Reported root number of mandibular second molars

Second molars	Country	One rooted (%)	Two rooted (%)	Three rooted (%)	Four rooted (%)	C-shaped (%)
Gulabivala *et al.* (2001)[68]	Burmese	4.5	73.1			22.4
Gulabivala *et al.* (2002)[83]	Thai	25.3	72	2.7		
Ahmed *et al.* *(*2007)[71]	Sudanese	4	86			10
Peiris *et al.* (2007)[91]	Sri Lankan		94			6
Al-Quda&Awawdeh *(*2009)[100]	Jordanian	2	87			10
Rwenyonyi *et al.* (2009)[101]	Ugandan		100			
Neelakantan *et al.* *(*2010)[74]	Indian		83	9		8
Miloglu *et al.* (2013)[33]	Turkish	-	-	-	-	-
Silva *et al.* (2013)[31]	Brazilian	9.5	83.5	3.5		3.5
Nur *et al.* (2014)[34]	Turkish	10	90			
Present study*	South African	2.6	94	1.9	0.5	(0.5) *

* C-shaped teeth were excluded from root number analysis and only noted as additional data

5.2.3 Three rooted mandibular molars

Three-rooted teeth are considered to be uncommon anatomical variations in mandibular molars and these teeth are reportedly more prevalent in patients of Asian ethnicity.[103] No studies describing the prevalence of three-rooted mandibular molars in a South African population could be found.

The three-rooted molars in the present study were classified as either radix entomolaris, radix paramolaris, or the presence of two mesial roots. The distribution of three-rooted mandibular molars is demonstrated in Table 14.

Table 14. Distribution of radix entomolaris, radix paramolaris and two mesial roots

	Radix entomolaris % (n)	Radix paramolaris % (n)	Two mesial roots % (n)
First and second molars combined	40 (6)	7 (1)	53 (8)

Few studies have reported data on three-rooted mandibular molars in patients of African descent. Ferraz and Pecora[75] found the prevalence of three-rooted mandibular molars in a Brazilian population to be different for participants of Asian descent (15,2%), African descent (7,5%) and Caucasian descent (6,8%). These findings however cannot be extrapolated to people living on the African continent. Other studies reporting findings of patients of African origin found less than four percent prevalence of three-rooted molars in mandibular first molars and no three-rooted second mandibular molar.[71,101,104] Rwenyonyi *et* *al.*[101] found no mandibular first or second molars (n=447) with more than two roots in a Ugandan population.

The incidence of radix entomolaris has been linked to ethnic origin, with Asian populations demonstrating the highest incidence of up to 30%.[105] Chandra *et al.*[103] found radix entomolaris in mandibular first molars in a South Indian population to be present in 13.3% of teeth evaluated in their sample.

A study of root anatomy of extracted mandibular molars in a Sudanese population[71] reported a three percent prevalence of three-rooted teeth in mandibular first molars. This study reported no second mandibular molars with three roots. Similarly, another study of extracted first molars in a Senegalese population reported a 3.12% incidence of teeth with a third root.[104]

The present study found a one percent prevalence of a third root in mandibular first molars and a 1.9% prevalence in mandibular second molars. When compared with other studies of African populations these figures are low for mandibular first molars and high for mandibular second molars.[71,101,104]

5.3 Root canal anatomy of mandibular first and second molars

Analysis of the root canal anatomy of mandibular first and second molars in the present study showed that the majority of mesial roots of mandibular first and second molars combined have two canals (80%) and approximately two-thirds of distal roots of mandibular molars (combined) to have one canal (66%). These findings concur with several previous studies.[73,83,100,106–110]

Middle mesial canals were demonstrated in 20% of mandibular first molars and 16% of mandibular second molars evaluated in the present study. Table 15 demonstrates the findings of the present study compared to previous published data.

5.3.1 The effect of age on canal anatomy

In the present study, the relationship between the age and root canal anatomy was evaluated. It was found that the samples from the older age brackets had an inconsistent tendency toward a higher incidence of middle mesial canals than those in the younger age groups. The results were however inconclusive. This phenomenon is in conflict with the findings of the study by Azim *et al.,*[85] who reported the incidence of middle mesial canals to be significantly higher in younger patients as compared to older patients. The same authors performed a regression analysis in their study, demonstrating age to have an effect, with increasing age resulting in a decreased prevalence of middle mesial canals. A possible explanation for these differences may be the differences in the methodology used. The Azim *et al.*[85] study used troughing under magnification and the present study analysed CBCT scans. Azim *et al.*[85] postulated that the lower incidence of middle mesial canals in an older population could be due to ongoing dentine deposition, obliterating the additional, smaller middle mesial canals with increasing age.

In contrast, Ballullaya *et al.*[88] cited the same biological process, namely secondary dentine deposition, as the method by which a vertical grove forms between the mesiobuccal and mesiolingual canals, leading to the creation of middle mesial canals. The findings of the present study appear to be in agreement with the latter assertion.

5.3.2 Middle mesial canals

Previous studies reporting the prevalence of middle mesial canals, including the results of the present study are summarised in Table 15.

Table 15. Prevalence of middle mesial canals including present study

Middle mesial canal prevalence					
Study	Year	Country	Sample size	Method	Prevalence (%)
Skidmore & Bjorndal[73]	1971	USA	85	*In Vitro*	0
Pineda & Kuttler[127]	1972	Mexico	600	*In Vitro*	0
Vertucci[128]	1974	USA	100	*In Vitro*	1
Pomeranz[129]	1981	USA	100	*In Vivo*	12
Fabra-Campos[107]	1985	Spain	145	*In Vivo*	2.1
Walker[130]	1988	Chinese	100	*In Vitro*	1
Fabra-Campos[131]	1989	Spain	760	*In Vivo*	2.6
Goel[89]	1991	India	60	*In Vivo*	15
Caliskan *et al.*[111]	1995	Turkey	100	*In Vitro*	3.4
Rocha *et al.*[112]	1996	Brazil	199	*In Vitro*	-
Kartal & Cimilli[66]	1997	Turkey	697	*In Vitro*	-
Zaatar *et al.*[113]	1997	Kuwait	147	*In Vivo*	0
Sperber & Moreau[104]	1998	Senegal	480	*In Vitro*	0
Zaatar *et al.*[114]	1998	Kuwait	49	*In Vitro*	-
Al-Nazhan[108]	1999	Saudi Arabia	251	*In Vivo*	0
De Carvahlo & Zuolo[115]	2000	Brazil	204	*In Vitro*	21.7

Wasti *et al.*[116]	2001	Pakistan	30	*In Vitro*	3.3
Sarkar[117] (deciduous teeth)	2002	India	10	*In Vitro*	70
Sert & Bayirli[25]	2004	Turkey	400	*In Vitro*	1.5
Marroquin *et al.*[118]	2004	Egypt	286	*In Vitro*	-
Villegas *et al.*[119]	2004	Japan	63	*In Vitro*	-
Jung *et al.*[120]	2005	Germany	42	*In Vitro*	-
Cimilli *et al.*[121]	2006	Turkey	102	*In Vitro*	-
Navarro[122]	2007	Spain	27	*In Vitro*	14.8
Pattanshetti *et al.*[109]	2008	Kuwait	110	*In Vivo*	-
Shahi[123]	2008	Iran	209	*In Vitro*	1
Arora and Tewari[124]	2009	India	100	*In Vitro*	-
Chen[110]	2009	Taiwan	183	*In Vitro*	6
Al-Qudah & Awawdeh[100]	2009	Jordan	330	*In Vitro*	6
Rwenyonyi *et al.*[101]	2009	Uganda	447	*In Vivo*	0
Karapinar-Kazandag *et al.*[125]	2010	Turkey	96	*In Vitro*	20
Gu *et al.*[126]	2010	Chinese	45	*In Vitro*	2.2
Wang *et al.*[32]	2010	Chinese	410	*In Vivo*	2.7
Kucukkaya *et al.*[63]	2014	Turkey	100	*In Vitro*	12
Azim *et al.*[85]	2015	USA	91	*In Vivo*	46
Nosrat *et al.*[84]	2015	USA	75	*In Vivo*	20
Sherwani *et al.*[87]	2016	India	258	*In Vivo*	28
Tahmasbi *et al.*[35]	2017	USA	122	*In Vivo*	16
Kantilieraki *et al.*[27]	2019	Greek	949	*In Vivo*	0.2
Present study	2019		753	*In Vivo*	18

The prevalence of middle mesial canals has been found to be varied when looking at the results in the Table 15. The lowest result being zeros and the highest being the outlier of Sarkar (2002) with a result of 70% in deciduous teeth. In 2015, Azim reported the second highest prevalence of 46% in a study undertaken in the United States of America. Sherwani reported the third highest prevalence of 28% in a study of an Indian population undertaken in 2016.

The current study reported a moderately higher prevalence rate of 18% with five other studies reporting between 15 and 25%.[35,84,89,115,125]

Figure 5: Middle mesial canal of a mandibular first molar

Figure 6: Middle mesial canal of a mandibular second molar

5.3.3 Middle distal canals

The present study found middle distal canals to be present in seven percent of mandibular first molars and less than two percent of mandibular second molars. In the absence of any published data, this seems to be the highest prevalence of middle distal canals observed in mandibular first molars reported in the scientific literature.

Literature regarding the prevalence of middle distal canals is scarce and previous findings range from 0.2% to three percent, with one outlier of 10% found in mandibular second molars of a Sudanese population.[71] A possible explanation for the higher prevalence of middle distal canals in mandibular molars may be that both the Sudanese and South-African studies included mainly patients of African origin. Future research into other African populations may be valuable in determining if an increased prevalence of three and more canals in the distal root systems could be attributed to ethnicity or geographical area.

Table 16 summarises previous studies and case reports regarding middle distal canals published in the literature.

Table 16. Prevalence of middle distal canals including present study

Study	Sample size	Population	Mandibular first molars %	Mandibular second molars %	Mandibular molars combined %
Goel *et al.*[89]	60	Indian	1.7		
Caliskan *et al.*[111]	100	Turkish			1.7
Gulabivala *et al.*[68]	139	Burmese	0.7		
Gulabivala *et al.*[83]	103 first, 54 second	Thai	1.9	1.9	
Sert *et al.*[142]	200	Turkish	1		
Ahmed *et al.*[71]	100 first, 100 second	Sudanese	3	10	
Al-Qudah and Awawdeh[92]	330 first. 355 second	Jordanian	1	0.3	
Current study	369 first, 384 second	South African	7.1	1.6	
Case reports					

Barletta *et al.*,[134] Reeh,[138] Chandra *et al.*,[136] Stroner *et al.*,[137] Beatty and Interian,[133] Kimura and Matsumoto,[140] Friedman *et al.*,[82] Lee *et al.*,[80] Ghoddusi *et al.*,[81] Jain,[141] Kottoor *et al.*,[135] Mushtaq *et al.*,[139] Baziar *et al.*[132]

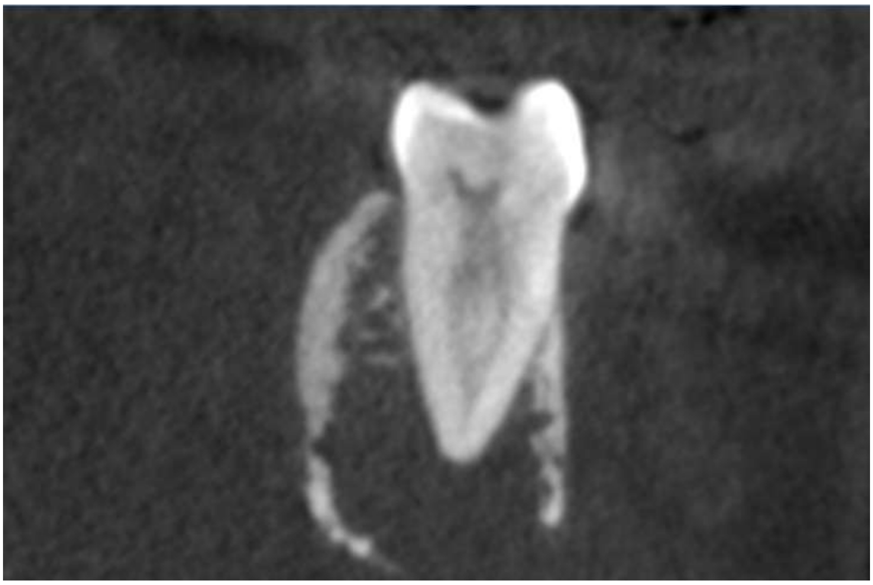


Figure 7: Middle distal canal on a mandibular first molars – coronal view

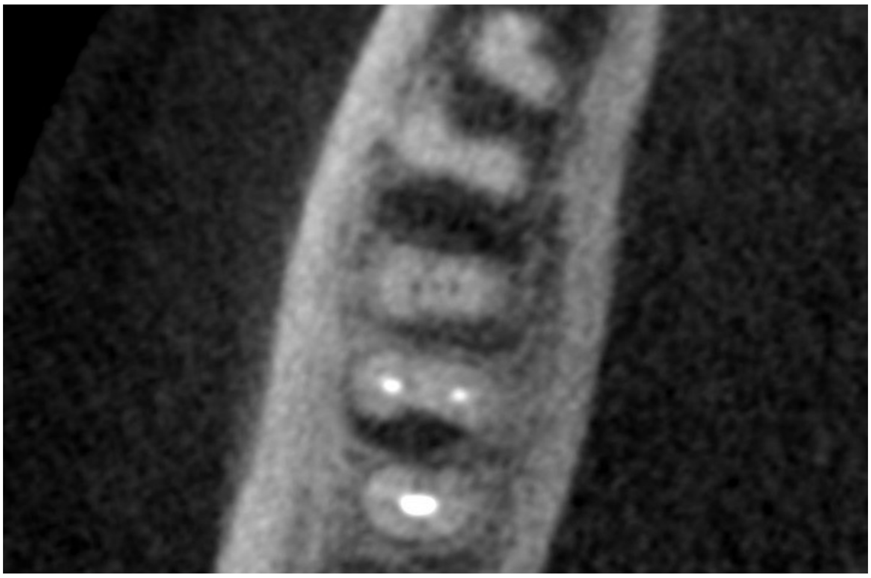


Figure 8: Middle distal canal of a mandibular first molar – axial view

5.4 Rationale for study design

Cone beam computed tomography was selected as the preferred methodology for use in the present study due to the large sample requiring evaluation. A large study sample was required to ensure reliability of the results in the event of a low prevalence of additional anatomy, such as middle mesial canals. Other methods of evaluation, such as the clearing and staining technique, may have been prohibitively time intensive. Furthermore, CBCT has been shown to be an accurate method of determining root and canal anatomy and has been used by several previous investigators.[29,61,143–145]

The resolution of CBCT is lower than micro-computerised tomography (MicroCT) scanning. A 2016 study found MicroCT technology to result in clearer images as compared CBCT.[146] MicroCT however cannot be used on living subjects due to the high level of ionising radiation. *Ex vivo,* CBCT has been demonstrated to be as reliable as physically troughing under magnification,[29] and as accurate as the clearing and staining technique (Neelakantan, 2010). Therefore, CBCT may be used as a reliable method for studying root and canal anatomy in large sample sizes.

In the present study, several CBCT scans were found to be difficult to interpret due to the severe curvature of the roots. This issue was especially problematic in certain mesial roots of mandibular molars. Severe root curvature may have resulted in the exclusion of some teeth from the present study, however, only a small number of teeth were excluded from the present study for this reason.

Examiner interpretation may have resulted in the erroneous classification of some root canal anatomy. These errors were more likely to occur in instances where the difference between two potential canal configurations was subtle. An example of such an error may exist in deciding between a Vertucci Type II or a Vertucci Type IV configuration. The only difference between these configurations is whether the canal system demonstrates one or two apical portals of exit. Such errors were unlikely to have had any meaningful impact on the results of the present study.

5.5 Limitations of study design

One limitation of this study was that the race of the subjects was not recorded. Previously, studies have suggested that race could influence dental root and canal anatomy.[147–149]The patients attending the Oral and Dental Hospital however self-report race, which may have led to inaccuracies in the data if included. Furthermore, given the complex history surrounding race in South Africa, data collection amongst racial lines may be a sensitive subject. South Africa has a diverse population regarding both ethnicity and race and the sub-population included in the present study was not homogenous along any racial lines. No assertions could therefore be made as to whether or not race or ethnicity of individuals may have impacted the results of the present study.

5.6 C-shaped canal systems

The prevalence of C-shaped molars was noted in the present study; however, it was decided not to classify C-shaped molars as the classification of these teeth was considered to fall outside of the aims this investigation. C-shaped root canal systems are classified using a unique system, i.e. Melton's classification,[150] with modifications and additions by Fan *et al.*[151] At the outset a high prevalence of these teeth in the mandibular molars of a South African population was not anticipated. Future research regarding the classification of C-shaped canal systems may however be valuable in a South African population, as a prevalence of nearly eight percent was found to exist in the mandibular second molars evaluated in the present study.

CHAPTER 6: CONCLUSIONS

In the South African sub-population investigated in the present study, the following conclusions were made:

- a diverse range of root number and canal configurations existed in mandibular first and second molars.
- root number and canal configurations fell within previously reported ranges except for the prevalence of middle distal canals in mandibular first molars (seven percent).
- middle mesial canals were found in nearly one fifth of mandibular first and second molars evaluated and fell within previous ranges, accepting the null-hypothesis.
- C-shaped canals were found in just over seven percent of mandibular second molars.
- A low number of three- and four-rooted mandibular molars were observed.
- Age and sex had no influence on root number or canal configurations in accordance with the null-hypothesis.
- the Vertucci classification system with the additions of Sert and Bayirli can be used to successfully describe root canal configurations in mandibular molars.
- CBCT is a viable modality to evaluate root and canal configuration.

In summary, the null hypothesis regarding root number and canal configurations if the variables of sex and age were considered, and the proportion of middle mesial canals in a South African sup-population was accepted as no significant differences could be found. The null hypothesis regarding the proportion of middle distal canals in a South African sup-population was rejected as a high proportion of this configuration was seen in mandibular first molars.

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APPENDIX A - DATA CAPTURING SHEET

General					Canal classifications								C-shape	Root classifications								Scan
	Nr	Scan date	DOB	Sex	T37_D	T37_M	T36_D	T36_M	T47_D	T47_M	T46_D	T46_M	C-shape	T37	T36	T47	T46	Ento	Para	2mesial	conical	voxel
1																						
2																						
3																						
4																						
5																						
6																						
7																						
8																						

SUMMARY

The aim of the present study was to classify the root number and the root canal configurations of human mandibular first and second molars in a South African sub-population using CBCT. The study design was a retrospective cross-sectional descriptive study with a sample size of 753 molars. The CBCT images of each individual mandibular first and second molar were evaluated by two examiners. Canals were classified using the Vertucci classification system, including the additions proposed by Sert and Bayirli. Root number was classified as either one, two, three, or four-roots.

Two-rooted molars were found in the vast majority of mandibular first and second molars and one- and three-rooted molars were uncommon. Half of all three-rooted molars presented with two distinct mesial roots. Four-rooted molars were extremely rare and found only in mandibular second molars. The most common canal type in the mesial roots of first and second molars was Type IV followed by Type I. The most common canal type in the distal roots of the first and second molars was Type I followed by Type V. More than two mesial canals (middle mesial canals) in mandibular first and second molars were present in about one-fifth of the sample. More than two distal canals were present in seven percent of mandibular first molars, which was higher than anticipated. C-shaped canal systems were found very rarely in mandibular first molars but in 7.7% of mandibular second molars. Sex and age had no statistical significance. It is important for clinicians to be aware that a number of mandibular molars may present with more intricate anatomy than expected during endodontic treatment and that this may affect treatment outcomes.

Keywords: Lower molars, canal configurations, middle mesial canals, middle distal canals, South Africa, CBCT

ETHICS APPROVAL

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.
- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 03/14/2020.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

16/08/2018

Approval Certificate
New Application

Ethics Reference No: 397/2018

Title: Root and canal configurations in mandibular molars using CBCT, with an emphasis on middle mesial canals

Dear Dr Sheree Tredoux

The **New Application** as supported by documents specified in your cover letter dated 3/08/2018 for your research received on the 6/08/2018, was approved by the Faculty of Health Sciences Research Ethics Committee on its quorate meeting of 15/08/2018.

Please note the following about your ethics approval:
- Ethics Approval is valid for 1 year
- Please remember to use your protocol number (**397/2018**) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:
- The ethics approval is conditional on the receipt of **6 monthly written Progress Reports**, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers; MBChB; MMed (Int); MPharMed,PhD
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health).

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